PRIORITY Criminal Justice NEEDS INITIATIVE

A project of the RAND Corporation, the Police Executive Research Forum, RTI International, and the University of Denver

Wearable Sensor Technology and Potential Uses Within Law Enforcement

Identifying High-Priority Needs to Improve Officer Safety, Health, and Wellness Using Wearable Sensor Technology

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EXECUTIVE SUMMARY

The development and advancement of wearable sensor technology (WST) offers opportunities for individuals to gain better insight into their own health and wellness by tracking various types of biomarkers: physiological measures that can indicate physical condition (e.g., blood pressure, body temperature) or physical activity (e.g., steps taken, perspiration, heart rate over time). In addition to personal use, corporate use of WST is viewed as a means to improve and facilitate better organizational decisionmaking, especially through health and wellness programs. Although many law enforcement officers might personally use various types of WST, agencies generally have not yet taken advantage of the technology to inform operational decisionmaking.

On September 18 and 19, 2019, a workshop was convened at the offices of the Police Executive Research Forum (PERF) in Washington, D.C., to examine the potential benefits of WSTs for improving individual officer safety, health, and wellness in law enforcement. This workshop was convened on behalf of the National Institute of Justice (NIJ) by PERF and the RAND Corporation. The intent of this workshop was to examine the current and near-term (i.e., in the next five years) state of portable WSTs, such as wrist bands, chest straps, and smart textiles, for collecting and analyzing officers' health-related biomarkers (as opposed to environmental sensors, such as air quality or noise) to inform operational decisionmaking. The goal was to assess what opportunities (e.g., outcomes associated with tracking to improve officer health) can be realized using these devices and what potential pitfalls (e.g., outcomes associated with invasion of officer privacy) should be avoided. This effort is one of many from a multiyear collaborative project, the Priority Criminal Justice Needs Initiative, to inform the research agenda of NIJ by developing expert-identified technology and policy needs on issues affecting the criminal justice system. Workshop participants were led through semi-structured discussions on three topics: (1) the current state of WST; (2) the intersection of WST and law enforcement interests, both for the

SELECTED PRIORITY NEEDS

RESULTS

Policy adoption

- Officers should be educated about the multiple uses and purposes of WST.
- Pilot testing should be conducted, and feedback should be collected on experiences.
- Outcome measures should be identified early in the process.

Policy adaptation

- Policies and processes for when and why data may be shared should be developed and implemented.
- A sequenced or phased approach should be developed for taking validated technology to the field for scaled evaluations.

Technology and data measurement

- Individual baselines should be established to account for differences among individuals.
- The state of the research should be monitored, and law enforcement and public expectations should be managed.
- A set of best practices should be defined for consumer wearable devices.

Technology and data usage

- Data should be encrypted at each layer, and end-to-end encryption should be employed.
- Guidance and education about how to interpret data and metrics should be developed for WST users.

individual officer and the agency; and (3) data privacy, ownership, and the public. Throughout the workshop, participants were asked to identify salient issues and specific needs to address them arising from the discussions.

Following the discussions, experts participated in a ranking exercise to identify the most important needs. Overall, 33 of the 61 identified needs were categorized as high-priority. These needs fell into four general categories: (1) policy concerns related to WST adoption, (2) issues related to potential law enforcement policy adaptation or change to address WST, (3) how WSTs collect data that are relevant for law enforcement, and (4) the interpretation and use of WST data within law enforcement. This report details the needs that emerged through this exercise and provides additional context from participant discussions.

WHAT WE FOUND

- Current WSTs are not yet sufficiently developed for law enforcement purposes overall. Although commercial products are inexpensive and portable—both key requirements for law enforcement—the devices lack the accuracy and precision needed to inform and support potential decisionmaking. In contrast, WSTs that are used in medical settings are capable of excellent accuracy and precision with high-quality data but are cost-prohibitive for wide distribution and are not portable.
- The workshop participants believed that the short-term focus should be on preparing for a time when the technology will be more applicable to law enforcement roles. The key is to obtain buy-in among law enforcement officers now—not for the current technology, but for devices developed in the future and the possible downstream effects on the field as WSTs are deployed to support officer safety and wellness, workforce retention, liability, and many other issues in law enforcement.
- The common thread across the wide-ranging expert panel discussions was decisionmaking. Currently, the intersection between WST and law enforcement is characterized by uncertainty. Participants reiterated that the applicability of WST to law enforcement will be proportionate to how well the technology can reliably inform decisions about an officer's daily activities. Devices need to seamlessly integrate with the technology that law enforcement already carries, measures need to be valid and reliable, interpretation of the data needs to be clear, and policies need to be in place for managing and monitoring the data. WST has the potential to provide critical information in cases that involve assessing an officer's ability to work and for commanders making choices about whether to pull an officer from assignments as a result.
- Given the promise of WST use within law enforcement, now is the time for law enforcement to participate in the development process. The participants agreed that the law enforcement specifications might not match the commercial industry standard (e.g., need for remote real-time monitoring, increased security, ability to use technologies during various critical incidents where bandwidth might be limited), so law enforcement needs to talk to—and be heard by—WST manufacturers. This includes the need to develop clear guidance on how to interpret data, describing how various bioanalytics inform outcomes, and creating law enforcement–specific use cases.

Devices need to seamlessly integrate with the technology that law enforcement already carries, measures need to be valid and reliable, interpretation of the data needs to be clear, and policies need to be in place for managing and monitoring the data.

New technologies often promise to revolutionize "old ways" of doing things, which can lead to a push from the public for law enforcement to integrate said devices to improve productivity or create new forms of accountability.

INTRODUCTION

Wearable sensor technology (WST) is defined as "a body worn electronics system integrating enhanced communications capabilities, locations and tracking capabilities, situational awareness and environmental sensing capabilities, physiological status monitoring capabilities, and respiratory protective equipment status" (InterAgency Board for Emergency Preparedness and Response, 2010, p. 1). Because of numerous technological improvements to Bluetooth; battery life and size; and global positioning system (GPS), sensor, and smartphone technology in recent years, WST adoption has increased dramatically in the personal-use commercial market (Aroganam, Manivannan, and Harrison, 2019). Commercial fitness trackers for individual use, in particular, have become more popular (Hanuska et al., 2016). This popularity has extended into law enforcement as well, in various ways: Law enforcement has drawn on the data collected by WST worn by others to obtain digital evidence during investigations (PERF, 2018a), and, because of rising popularity, many individual officers may have purchased wearable devices for their own personal use (Holst, 2020). WST could inform operational decisions regarding officer safety and wellness, offer the ability to remotely monitor critical incidents, and inform personnel or staffing selections for assignments (e.g., make changes to officers' duties in response to indicators of prolonged sedentary behavior or chronic stress indicators while on duty) (Arroyo, 2019; Bedford, 2019; Cashion, 2018). Future scenarios have also been envisioned for WSTs that can, for example, track and analyze biomarkers related to stress in real time for the purpose of detecting when an officer might be in a stressful situation and informing the officer, his or her partner, or his or her leadership of the potential need to withdraw. Unfortunately, the current state of the technology, in terms of accuracy, reliability, and various other factors, might not yet be adequate—even for many of the simpler applications envisioned for law enforcement—for reasons that will be described in more detail later.

Police agencies are sometimes pressured to make large-scale technology choices with limited guidance or established best practices. In such cases, the new technology might be commercially available and even used by individual officers to help make personal decisions while on duty. Devices can even be popular across wide segments of the public or ubiquitous for personal use. New technologies often promise to revolutionize "old ways" of doing things, which can lead to a push

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from the public for law enforcement to integrate said devices to improve productivity or create new forms of accountability for officers (typically in response to high-profile events). When novel technologies are rapidly and widely adopted for personal use, individuals can have misconceptions regarding the true capabilities of these technologies or the challenges of large-scale deployment for corporate use. Acquisition for law enforcement can seem to be an easy choice to solve complex problems with limited drawbacks, and the generation of significant governmental funding streams or direct aid to assist law enforcement agencies can create pressure for a rapid timetable of adoption. As a result, demand for a technology can rapidly outpace the research and practical experience in law enforcement agencies that are needed to create good policy or best practices for use in law enforcement (Jackson et al., 2020).

Although the sequence of events just described is consistent with WST to date and could accurately reflect the future WST trajectory in law enforcement, it is also consistent with a recent scenario with another type of police technology: body-worn cameras (BWC). Prior to their current large-scale adoption, BWC had been commercially available and were used by individual officers, often at their own expense (Miller, Toliver, and Police Executive Research Forum, 2014). BWC had long been popular with a diverse set of stakeholders, including police, members of the community, and reformers (Andrews, 2019), and wide acquisition was actively encouraged following the national unrest resulting from events in Ferguson, Missouri, during 2014. Departments subsequently justified BWC procurement as a means to improve police legitimacy (PERF, 2018b), although research has cast doubt as to the potential effect of BWC on legitimacy (see PERF, 2017). Although a considerable amount of research on BWC has been developed in recent years (Lum et al., 2019; White, Todak, and Gaub, 2018), much of it has been driven by the rapid adoption of BWC and the lessons learned from acquiring a new technology quickly.

> The time to establish usage rules, privacy protections, the role of the agency in using the data, and how to address public information requests is *before* a rollout of the technology.

Initial popular opinion often considered BWC a panacea to the ills of policing, but some in the policing field cautioned against such an association at the time and emphasized the need for strong, clear policy before implementation (Miller, Toliver, and Police Executive Research Forum, 2014). The time to establish usage rules, privacy protections, the role of the agency in using the data, and how to address public information requests, however, is *before* a rollout of the technology (PERF, 2017). The same advice can be given regarding WST. WST, unlike BWC, has not had a "Ferguson event" to initiate a rapid acquisition schedule, and this fact can be used to the field's advantage to get ahead of the potential curve given some of the similarities between the trajectory of BWC and the potential path of WST adoption.

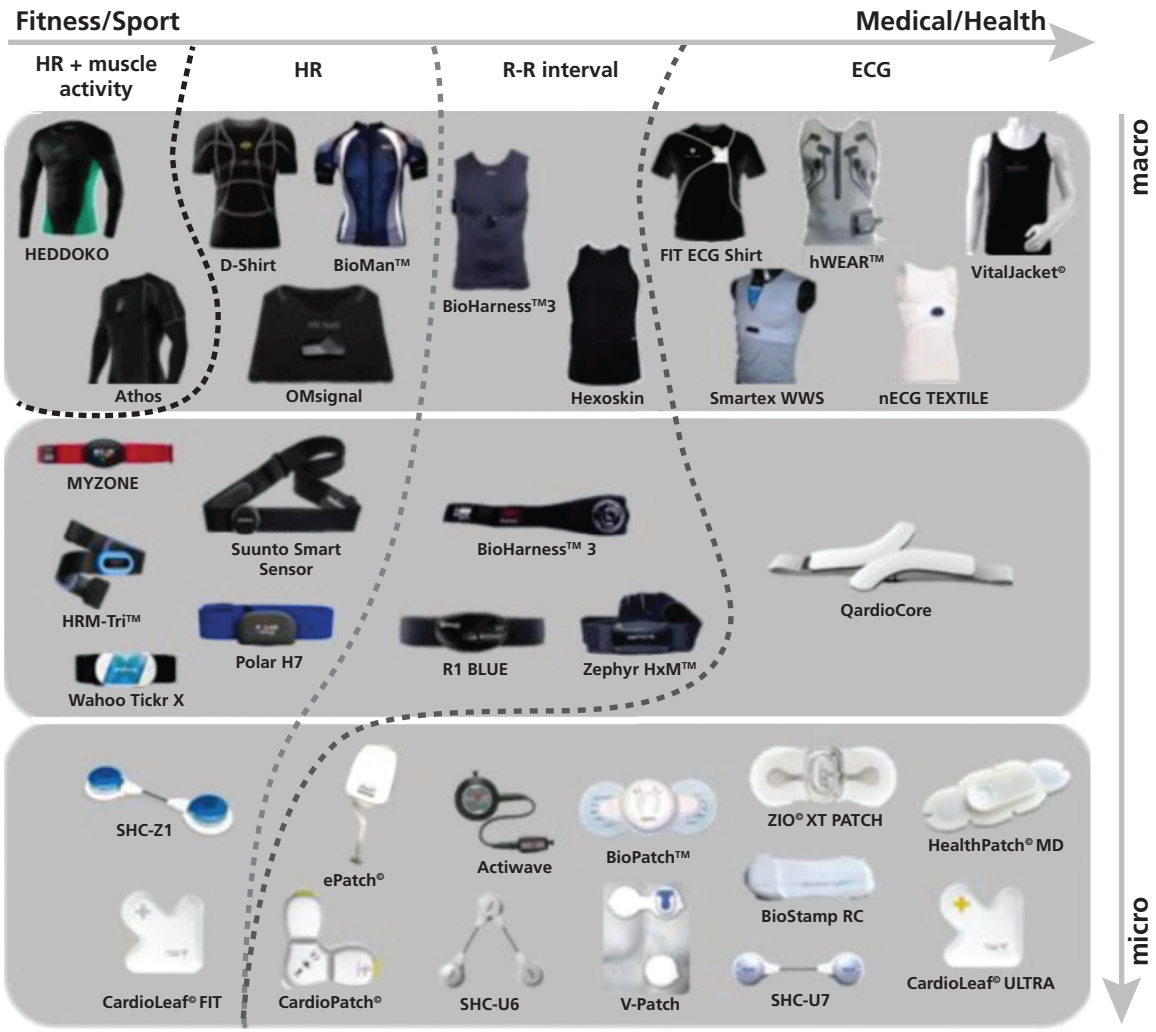
The Current State of Wearable Sensor Technology

Although numerous potential applications exist for WSTs, and although they can collect many different types of data (Inter-Agency Board for Emergency Preparedness and Response, 2010), the focus of the workshop was limited to the measurement and tracking of indicators of personal health and wellness. In this section, we briefly describe the state of WST in terms of capabilities for measurement, types of devices, and applications for law enforcement to provide the reader with the necessary context for the results of the workshop.

Measurement

WSTs, which we refer to as *wearables* when we describe the commercially available mass-market devices, contain sensors worn on the body to collect biomarkers from the user. For example, wristwatches are a common form of wearable that often are used to measure a biomarker associated with physical activity (e.g., step count, movement) using a GPS sensor and accelerometer embedded in the device. Smartwatches and fitness trackers dominate commercial markets (Hanuska et al., 2016), but WSTs are currently available and under development in a variety of form factors, such as clothing and textiles, harnesses and straps, pills, and tattoos, to name a few (e.g., see Guk et al., 2019). Various examples are shown in Figure 1.

Figure 1. Examples of Wearable Sensor Technology Devices



SOURCE: Dias and Cunha, 2018, p. 17 (CC BY 4.0).
NOTE: ECG = electrocardiogram; HR = heart rate; R-R interval = time difference between successive heartbeats.

WST can also collect various other biomarkers. Other common biomarkers include heart rate, heart rate variability, atrial fibrillation, blood pressure, maximal oxygen consumption, respiration, and skin temperature (Hung, Babin, and Coberly, 2016; Majumder, Mondal, and Deen, 2017; Seshadri et al., 2019). Newer devices are being developed to capture other biomarkers, including perspiration or sweat chemistry, saliva composition, and even biomarkers associated with psychological conditions, such as mental stress. The ability to collect real-time feedback from individual users on a suite of behavioral, physiological, and psychological indicators demonstrates the potential for this emerging technology to revolutionize health and well-being.

Although there is significant potential for wearables to change how health and wellness are managed, personally and for populations, these technologies are still in the early stages of development and are limited by several technical challenges. For example, form factor is a key component of WST that affects both wearability and the validity (accuracy) and reliability of data that are collected.[1] Studies conducted within clinical settings have found that patients and clinicians prefer noninvasive, body-worn systems with flexible, small sensors (Sazonov and Neuman, 2014). Although it improves wearability, the miniaturization of sensors is expensive and might affect the accuracy of data collected from the user because the sensors draw information from only one small portion of the body (Sazonov and Neuman, 2014; Shcherbina et al., 2017). Also, different wearable devices have been found to be accurate in some conditions, such as while the user's heart rate is resting or has been elevated for a prolonged period, but readings deteriorate with changing activity levels (Bent et al., 2020). Challenges have also been observed regarding the signal strength from

the bodily processes being measured to the WST device; such delays are often caused by the skin serving as an information barrier (Heikenfeld et al., 2018). Other challenges include reliability issues associated with skin color (Kim, 2017) and body mass (Chan et al., 2012).

Types of Devices

Although there is a variety of wearable devices, they can generally be categorized into two grades of devices based on the quality and reliability of the data they produce: those for casual, individual, or personal use and those for professional (often medical or scientific) use. The first category consists of wearables that are available for individual purchase in commercial markets, such as wrist- or chest-worn fitness trackers. Smartwatches, for example, are popular devices that typically measure heart rate (via photoplethysmography) and step count (via accelerometer) with an output that is immediately available on the device's digital interface. These devices often feature connectivity to a mobile device, such as a cell phone, to collect and track additional data, and they possess a substantial battery life while not using such features as the GPS function (Aroganam, Manivannan, and Harrison, 2019; Pithadia, 2019). The accuracy of wrist-worn fitness trackers has generally been found to be low, with some features, such as step count, showing higher validity than others, such as distance, energy expenditure, total sleep time, sleep efficiency, and heart rate (Dondzila et al., 2018; Evenson, Goto, and Furberg, 2015; Evenson and Spade, 2020; Sears et al., 2017).

In contrast, WSTs are increasingly used in more-professional settings, such as medical settings, to gather detailed information about a patient's health status. For example, iHealth products measure blood glucose or blood pressure (Hänsel et al., 2015). Medical WSTs have been used to help address various aspects of health, such as metabolic issues; cardiovascular and gastrointestinal monitoring; poor sleep; neurology; movement disorders; mental health; maternal, prenatal, and neonatal care; pulmonary health; and environmental exposures (Dunn, Runge, and Snyder, 2018). Data collected by WSTs used in medical settings are typically of higher quality and provide more-reliable readings from the user. Although this technology can be highly useful in a medical setting, these devices are very expensive, offer limited compatibility across platforms, have limited battery life, must be worn for extended periods of time, and are typically much bulkier and less practical for everyday wear (Dunn, Runge, and Snyder, 2018). These devices also require personal calibration to produce more-accurate measurements while monitoring a patient's health, and applications often require analysis of large amounts of data. Data processing steps are being developed to further advance the analytic capabilities of this technology (Guk et al., 2019; Witt et al., 2019).

Wearable Sensor Technology and Law Enforcement

Most of the research and development activities focus on personal and medical use of WST, not workplace application, and they seek to strike a balance between optimizing battery life and optimizing memory storage (King et al., 2017). Work is acutely limited in the law enforcement technology space. The U.S. Department of Homeland Security funded an examination of first responders' use of WST. Although this work was initially focused on firefighters, applicability to law enforcement was recognized, and subsequent efforts explored use among other first responders (U.S. Department of Homeland Security Science and Technology Directorate, 2017; U.S. Department of Homeland Security, undated). The Johns Hopkins University Applied Physics Laboratory, supported by the NIJ, conducted a feasibility study of current commercial products to assess WSTs with a specific focus on law enforcement use (Hung, Babin, and Coberly, 2016). Additionally, two departments have tested different wrist-worn WSTs; the Seattle Police Department has investigated the use of the Garmin wristwatch (Hickman et al., 2011), and the Durham Police Department has examined the use of the Empatica E4 wristband (Warren-Hicks, 2017). Outside this scientific testing, the Charlotte-Mecklenberg Police Department has pledged to track each time an officer draws a weapon and points it through new holster monitor sensors (Zhou, 2020). This technology, which is also known as *signal sidearm sensors*, has been distributed to every officer in the department along with the added requirement that officers report specifics surrounding why they drew the weapon and what they did with it. In addition to the Charlotte-Mecklenburg Police Department, several agencies in California are reported to be implementing some forms of mobile biometric technology to confirm the identity of an individual during a stop (Maass, 2015). These agencies include the Brentwood Police Department, Los Angeles County Sheriff's Department, Pasadena Police Department, Marin County Sheriff's Office, Orange County Sheriff's Office, San Diego Association of Governments, San Diego Police Department, Carlsbad Police Department, and San Jose Police Department (Maass, 2015).

The U.S. Army's Warfighter Physiological Status Monitoring program showcases another area of promise for WST

application in law enforcement and other first responder groups (Shaw et al., 2004). This program used a suite of sensors embedded in clothing fabric, chest harnesses, wrist devices, and wrist devices with chest straps to demonstrate a promising hybrid approach for the incorporation of multiple forms of sensors (Cashion, 2018; Silberglitt et al., 2017). The key form factor in this WST application is the chest harness, including sensors reporting data on cardiac activity, respiration, movement, and a measure of quality assessment (e.g., how well the sensor is working, how reliable the measurement is) for these functions. The chest harness is also able to measure posture, speed, distance, acceleration, and movement. Programs of this kind demonstrate the potential (if not yet the practical reality) for WST to monitor many different potential metrics with the fidelity and reliability needed to inform individual and agency decisionmaking in law enforcement.

There are nevertheless many challenges to address before WST can be deployed in law enforcement. Most WSTs available today exhibit low accuracy and varying consistency during different activities or across different demographic factors (Shcherbina et al., 2017). Officers and agencies might have valid hesitation in adopting WST because of concerns around data privacy, security, and use in agency decisionmaking. Some also consider the broader ethics of the large-scale implementation of WST for collecting personal health data from law enforcement to be an underdeveloped subject (Nebeker et al., 2017). These and several other themes emerged from the discussions of the expert panel, which we describe in the next section.

Methodology

To inform a research agenda for NIJ and other stakeholders regarding the use of WST to improve officer safety and well-being, we convened a workshop at the offices of the PERF in Washington, D.C., on September 18 and 19, 2019. This workshop was organized by the RAND Corporation and PERF on behalf of NIJ. A diverse expert panel of law enforcement practitioners, researchers, and technology developers from across the country was convened and led through semi-structured discussions on three topics: (1) the current state of WST; (2) the intersection of WST and law enforcement interests, both for the individual officer and the agency; and (3) data privacy, ownership, and the public. Throughout the workshop, participants were asked to identify needs arising from the discussions.

Following the discussions, participants were led through a ranking exercise to generate a prioritized set of needs that was then clustered into three tiers: high, medium, and low.

Officers and agencies might have valid hesitation in adopting WST because of concerns around data privacy, security, and use in agency decisionmaking.

The results described in this report should be of interest to law enforcement agencies, technology manufacturers, the research community focused on officer health, and public policy and privacy advocates involved in the collection and use of health data. For a detailed description of the panel selection process, workshop agenda, and prioritization methodology, please consult the technical appendix included with this report

RESULTS

During the panel discussion, the workshop participants identified a total of 61 needs. During the prioritization, 33 of these needs were identified as high-priority (i.e., they fell into the top tier of needs in the prioritization). These 33 high-priority needs are shown in Table 1. Note that in several cases when participants identified a problem or opportunity, they identified multiple potential needs associated with the same issue. Issues that have multiple associated needs are grouped as such in the table.

After the workshop, we assessed the needs and grouped them into two broad operational categories related to the two topical themes of the workshop: (1) policy and (2) technology and data. Respectively, these categories refer to solutions that can be led by police with input from other stakeholders and solutions that can be led by other stakeholders (e.g., technology developers) with necessary input from law enforcement to tailor outcomes for law enforcement. We chose to divide these two broad categories into four subcategories to better facilitate a description of the content and context that the workshop participants discussed. We used our judgment to sort each identified need into one of these subcategories after the workshop.

Table 1. The 33 High-Priority Needs, by Category

Issue or Opportunity	Potential Solution
Policy adoption	
It might be challenging to achieve acceptance and utility of WST-based programs or initiatives at the agency level.	• Identify outcome measures early in the process.
The costs of WST (e.g., start-up, data storage, maintenance, analysis, training, equipment) are significant.	• Conduct research on the return on investment of WST.
Law enforcement agencies and officers have shown a willingness to wear and use WST.[a]	• Secure buy-in through policy protections. • Conduct training to acclimate officers to WST. • Educate officers on potential positive and negative uses of WST. • Educate officers on the multiple uses and purposes of WST. • Conduct pilot testing and collect feedback on experiences.
New officers or recruits might have different expectations for a policing career, are potentially more aware of their health, and might be willing to try new technology.[a]	• Introduce WST in academy training to increase acceptability. • Encourage departments to make it known that they care about officers and officer health. • Increase self-awareness by encouraging officers to track themselves at home to collect baseline or resting data.
There are too many devices to choose from, and there is inadequate information about their performance.	• Take a systematic approach to deciding what device or product to use.
Policy adaptation	
WST data are sensitive, personal information and need to be protected by strong security.[a]	• Adopt and implement policy and process controls. • Treat WST data like other law enforcement–sensitive data.
It is difficult to change officer behavior without the ability to provide assessment of "how they are doing" over time.	• Provide support for officers through coaching, mentorship, and evidence-based programming.
Some fear that WST data would be used against law enforcement officers.[a]	• Partner with labor associations. • Develop and implement policies and processes for when and why data may be shared.
Demand from other entities and stakeholders to access WST data is increasing.[a]	• Establish policies for when to collect data, how often to collect data, how to retain data, and how to secure data. • Develop and implement policies for data sharing (i.e., what data should be shared, when, why, how, and with whom). • Understand how third parties (e.g., litigious agencies) could compel disclosure of data.
There is uncertainty about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Implement guidance and education for users on how to interpret data and metrics.
There has been a shift in how law enforcement takes care of its personnel, and there has been greater focus on officer safety and wellness, with a focus on creating better conditions for officers so that they can do their jobs better and for longer periods of time.	• Provide coaching, mentoring, and evidence-based programming for officers to help them understand the information and data and techniques for using them to make improvements.
The effectiveness of using the technology to improve officer safety and wellness is uncertain.	• Develop a sequenced or phased approach to taking validated technology to the field for scaled evaluations.
Technology and data measurement	
Individualizing or personalizing data metrics that come from WST is challenging.	• Establish individual baselines to account for differences across the individual.

Table 1—Continued

Issue or Opportunity	Potential Solution
There are general misconceptions that WST is more advanced than it is, and there is public confusion about WST.[a]	• Evaluate technologies based on technology readiness levels. • Monitor the state of the research and manage law enforcement and public expectations.
Uncertainty remains about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Conduct validation studies on existing sensor technology. • Review literature; conduct research on tests, sensors, biometrics, and bioanalytics and how they inform selected outcomes; or do both.
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Conduct validation studies of WST devices, and conduct reliability studies as technology changes. • Define a set of best practices for consumer wearable devices.
Technology and data usage	
WST data are sensitive, personal information and need to be protected by strong security.	• Encrypt data at each layer and employ end-to-end encryption.
Uncertainty remains about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Develop guidance and education for users on how to interpret data and metrics. • Determine users and uses of WST devices and data.
There are too many devices to choose from, and there is inadequate information about their performance.	• Develop a framework for uses of devices and data (e.g., use cases).

[a] This issue or opportunity has multiple associated needs, not all of which were ranked as high-priority. The other needs associated with this problem or opportunity can be found in the complete list of needs in the technical appendix.

The solutions classified under policy are divided into adoption and adaptation subcategories, while the solutions under technology and data are divided into measurement and usage subcategories:

- **policy adoption** addresses issues with the acceptance of solutions by law enforcement
- **policy adaptation** involves the new behaviors and policies that will be necessary if and when WST is introduced
- **technology and data measurement** addresses what information is gathered and how it is collected
- **technology and data usage** involves how information is interpreted and used.

The total list of needs, sorted by tier and category, can be found in Table A.3 in the appendix. Of the 61 needs,

- 17 (28 percent) were related to policy adoption
- 24 (39 percent) were related to policy adaptation
- 13 (21 percent) were related to technology and data measurement
- seven (11 percent) were related to technology and data usage.

High-Priority Needs

Eleven (33 percent) high-priority needs were related to policy adaptation, 11 (33 percent) were related to adoption, seven (21 percent) were related to technology and data measurement, and four (12 percent) were related to usage. Notably, despite only 17 of the 61 total needs pertaining to policy adoption, 11 (33 percent) of these needs were identified as high-priority. Four policy adoption needs called for some form of education or the adoption of training to familiarize offices with WST. Adoption needs also called for conducting research on the return on investment and pilot testing of WST, along with identifying outcome measures early in the process of incorporating WST into everyday use. Others highlighted the goal of securing buy-in through policy protections, along with systematically deciding what devices to use. The rest of the needs in this category identify as opportunities (1) the apparent willingness among officers to adopt WST for personal use and (2) the potentially broadening awareness of health in law enforcement among new recruits, and these needs describe ways to capitalize on these opportunities to promote effective adoption of WST in agencies. These actions include establishing policy protections to secure buy-in, training and educating officers on WST and potential positive and negative uses, conducting pilot testing to collect feedback from officers, introducing WST in academy training, actively communicating a concern for officer health

within agencies, and encouraging officers to track their health data at home to increase self-awareness.

Participants also identified 11 high-priority policy adaptation needs. Identified problems and opportunities in this category include the sensitive nature of WST data, uncertainty about what metrics are meaningful, questions surrounding the effectiveness of technology in officer safety and wellness, shifting priorities within law enforcement, increased demand from other stakeholders to access WST data, difficulty quantifying changes in officer behavior, and fear of WST data being used against the law enforcement officer in some manner. Participants prioritized implementing education for users on interpreting metrics, along with developing sequenced phase approaches to evaluating validated technology to address measurement and effectiveness concerns. When considering how priorities have shifted within law enforcement and how difficult behavioral changes for officers may be without assessment, participants suggested a need for coaching, mentoring, and evidence-based programming to understand the data and provide support. Finally, participants also noted several policy adaptation needs pertaining to issues with data sensitivity, fears about how WST could be used against officers, and properly sharing data. The needs included proactively establishing policy and processes for collecting and sharing data, treating WST data like other law enforcement–sensitive data, partnering with labor associations to ensure that officers are treated fairly, and understanding how third parties could compel disclosure of that data.

Participants identified seven technology measurement needs. These needs pertained to the many uncertainties still associated with WST. Participants noted general misconceptions among officers and the public about the current capabilities of WST, what WST can or should measure for law enforcement use, how to account for individual variation in data gathered from WST, and how to identify useful devices and adequate performance metrics among a diverse and expanding field of products. Establishing baselines to account for individual variability in each officer was seen as a potential solution to challenges with individualization. Five of the potential solutions called for evaluations and studies of the technologies, including evaluations of technology readiness levels; validation studies of WST (specifically sensor technology) and advances in reliability; and general monitoring of research literature to manage expectations of agencies and the public. Finally, participants identified a high-priority need to define a set of best practices for the use of wearable devices.

These same concerns with uncertainty were reflected in the high-priority needs pertaining to technology usage. To clarify uncertainty on what data can and should be measured for law enforcement, participants prioritized the development of guidance and education for users on how to interpret data. Participants also highly ranked two needs to determine who should use WST and how, including one potential solution that called for the development of a framework to help determine how devices and data should be used (e.g., create use cases). In response to concerns about the sensitivity of WST data, participants prioritized a need for employing end-to-end encryption to encrypt data at each layer.

DISCUSSION

The intersection between WST and law enforcement is defined by uncertainty. Given the nascent state of WST, the participants largely agreed that WST would not be employed on a large scale or in a systematic way to inform operations in the near term. They recommended, however, that law enforcement, researchers, and developers begin working together now to prepare for WSTs before they are deployed on a large scale. The timing presents a significant opportunity for policing to address the policy questions associated with WST. Addressing the policy questions up front could guide technological development by providing feedback to developers and could prevent a repeat of BWC adoption, in which the acquisition rate far exceeded the knowledge base or policy framework. The

Given the nascent state of WST, the participants largely agreed that WST would not be employed on a large scale or in a systematic way to inform operations in the near term.

> One expert stated that supporting personnel health is like being on an airplane and putting on one's own oxygen mask before helping one's neighbor—a healthier officer will serve his or her community better.

high-priority needs reflect fundamental questions surrounding the implementation (as a matter of policy) and the veracity (as a matter of technology) of WST, with the ultimate goal of enhancing law enforcement's ability to use WST for active decisionmaking. Although these conversations must continue as the technology evolves, the needs identified in this report provide a starting point to inform these efforts.

This section provides further context from the workshop discussion on the identified needs, organized by the four need categories developed as a result of responses at the meeting (i.e., policy adoption, policy adaptation, technology and data measurement, and technology and data usage). Although statements in this discussion should be presumed to be derived from the opinions and assertions of the workshop participants, references to other literature sources have been included where appropriate to provide more detail and support for the assertions and opinions discussed by the participants during the workshop (for example, where a participant might have mentioned a program or policy implemented by an agency and this program is described in a journal or news article).

Policy

Adoption

The expert panel noted some major issues that law enforcement agencies will face when seeking to adopt WST: specifically, the myriad devices available and limited knowledge about which devices work best for which purposes. Although some lessons can be learned from law enforcement experiences adopting other technologies, such as BWC, WSTs are somewhat different because they are not monolithic in form and function. Although vender differences exist for such technologies as BWC, radios, and even records management systems, the data that each of these technologies collects are generally the same (e.g., BWC collect video and sound when activated). In contrast, WST consists of a much broader variety of devices with different collected data, purposes, and functionalities, as well as unique limitations and challenges.

As a result, participants believed that police leaders likely will be required to navigate a much larger and more complex market when adopting WST as opposed to other types of policing-related technologies. In response to this problem, the participants suggested the need for agencies to use a systematic approach when selecting a product. The idea is to begin with a goal (i.e., what specific aims will be achieved by using WST?) and then assess which specific devices will be most helpful in accomplishing that goal. Law enforcement associations and membership organizations will be helpful resources in the adoption phase because they can facilitate information-sharing between agencies. This will help police leaders identify clear objectives that can be achieved using WST devices and learn from other similar types of agencies through their experiences with WST. Given the costs of purchasing new technologies, participants stressed that it will be critical for police leaders to gauge what types of devices might work for their agencies and avoid actions that agencies find to be too costly.

Police leaders also will face the challenge of securing buy-in from officers prior to implementing WST. The participants noted that there are two dimensions to this issue: (1) the acceptability of WST as a tool in policing and (2) the willingness of officers to wear and use WST. Experts discussed how a growing number of police leaders are beginning to understand the need for agencies to support the mental and physical health of their personnel. One expert stated that supporting personnel health is like being on an airplane and putting on one's own oxygen mask before helping one's neighbor—a healthier officer will serve his or her community better. Experts encouraged police leaders to actively take steps to demonstrate their concern for officers' health and wellness and embrace new policies and programs to that end, because doing so will increase the legitimacy of a proposed WST program and mitigate acceptability concerns. For example, one law enforcement participant's agency implemented a smartphone application that provides officers with access to wellness resources.

With regard to acceptability, the experts largely agreed that growing numbers of officers are likely to have favorable opinions of WST, because devices are often used personally and the technology development has coincided with a broader cultural shift in policing that values officers' health and wellness. One expert explained that those in the profession today want and expect their health and wellness to be an agency priority and are thus more agreeable to these types of programs. Furthermore, participants suggested that there is a generational shift occurring within the police workforce because younger officers are more likely to have grown up with technology and are thus more comfortable with it.

Although health and wellness are increasingly considered foundational to effective policing, experts did recommend other strategies to mitigate acceptability concerns with WST among officers. One approach could be to introduce WST during academy training, when new officers are learning the norms and values of their agency and the profession writ large. WST would be given to officers as part of their standard-issue equipment and would be treated as just another part of the policing toolkit. For experienced officers, WST can be introduced by someone with the credibility to discuss health and wellness topics, such as a physician, rather than a supervisor. Explaining the potential benefits of WST to officers, such as reduced insurance costs, validated disability claims, or monitoring of work-related injuries, can be helpful to promoting acceptability as well. Providing officers with WST early in their careers offers the benefit of establishing baseline health metrics that officers can monitor throughout the course of their careers, making the devices a much more meaningful way to foster health and wellness. Experts also suggested that police leaders should encourage officers to track their metrics not only while working but also at home to capture an individual's universe of stressors and what strategies might be effective for mitigating their impact.

Police leaders must also find ways to ensure that officers wear and use WSTs. According to the experts, one way to do this is to deploy devices that can be used for multiple purposes, beyond collecting health data alone. If WSTs can help officers complete other routine tasks more efficiently, they will come to rely on these technologies. For example, devices might include functions that collect information to aid in report writing, help with language translation, or replace the two-way radio as a communication device. At the same time, experts cautioned that WST might have negative implications or unintended consequences that must be considered. For example, agencies that deploy WST might see impacts on recruitment if certain individuals self-select out of the application pool to avoid wearing the devices. Further research is needed on these and other potential impacts.

Another way to encourage officers to wear and use WST is to pilot test different devices prior to full adoption. Participants suggested that, as part of pilot testing, agencies should collect feedback directly from officers on their experiences with each device. Given the wide variety of possible sensor types (e.g., shirts, wristwatches, chest bands), it will be important for agencies to assess which devices officers prefer to wear and how these devices perform in real-life situations that officers encounter. Some experts noted that when officers are involved in discussions about technology acquisition, they are more likely to support implementation efforts (e.g., see Miller, Toliver, and Police Executive Research Forum, 2014; Strom, 2017). The experts also recommended referencing the experiences of other professionals, such as military service members or firefighters, in adopting WST to understand what devices might work best for the conditions in which officers are likely to work. Experts suggested that, once an agency has determined that it will implement WST, it should provide officers with training that is designed to acclimate officers to the design and functionality of the devices.

Ultimately, buy-in will depend on policy protections implemented by agencies that clearly outline how WST will be used. For example, experts noted that the officers might have several

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procedural concerns about WST, such as the potential for use in discipline or discrimination. Officers also might worry about bearing the burden of higher health insurance premiums. Experts agreed that officers simply would not use WST if they believed that the devices ultimately would be used against them. Agencies will need to take steps to ensure that data collected from wearable sensors are used to inform strategies that support officers' health and wellness and improve police operations.

Adaptation

Implementation of WST will require agencies to adapt current policy frameworks both to outline the purpose and use of devices and to govern critical aspects, such as data sharing and data security. The data collected by WST are highly sensitive, providing intimate, minute-to-minute details about the behavioral and physiological status of specific individuals, and thus will require strong, comprehensive protections. Experts agreed that police leaders should engage labor associations when developing policies to ensure that they account for officers' concerns. The participants explained that specific policies will need to clearly guide what data are collected, in what circumstances, how long these data are retained, and what security protocols will be in place to protect existing information. Agencies will be required to implement their own policies, but the experts also suggested that a national standard policy could be helpful.

According to the participants, the first step in this process is deciding who or what entity will establish these criteria and make administrative decisions about WST data management. This could be the chief or sheriff, for example, or other entities, such as medical staff or such departments as human resources, information technology, or even training. The experts also discussed the possibility of a "privacy officer," who would have expertise in law and technology and be specifically tasked with managing all aspects of how agencies collect and manage data, including from WSTs. As an alternative, the experts suggested a WST model in which data are collected and retained by an authorized third party, such as a medical clinic or a research institute. The third party also would be responsible for analyzing data and providing training to officers and opportunities for wellness optimization. This structure might be favorable to officers who are concerned about WST, because agencies would not see the data and would rely on the interpretation and recommendation of a qualified expert to make operational decisions. One expert likened this approach to benefits providers who have access to employee health records and can notify a police chief or sheriff if an officer should be placed on light duty for a legitimate medical reason without disclosing the details of the officer's medical history.

As a security measure, only the minimum amount of data operationally necessary should be collected, and data should not be retained for prolonged periods of time.

Strict guidelines will need to be established for how data are shared internally. Some experts recommended treating WST data like any other law enforcement–sensitive data to ensure that they enjoy the same safeguards. Other experts believed that data belong to the users from whom they are collected, allowing users to make decisions about how the data are shared and, furthermore, allowing the data to be transportable if officers leave the agency for any reason. Treating data as property in this way involves a host of complex issues related to ownership, identity, and privacy, however, and assigning ownership rights to an individual's data in this way might not be a simple matter (Kerry and Morris, 2019).

Experts agreed that any system will have vulnerabilities, and extra care must be taken within the context of WST to understand and address them. As a security measure, only the minimum amount of data operationally necessary should be collected (a practice known as *data minimization*), and data should not be retained for prolonged periods of time.[2] This has a logistical benefit as well, because WSTs can collect vast amounts of information that might be challenging to use and expensive to store. Although most states have data retention laws, which gained wider public understanding because of BWC video storage issues (Miller, Toliver, and Police Executive Research Forum, 2014; PERF, 2017), policy should be adapted to note an explicit reason why specific WST-sourced data points would be collected and for how long the data would be stored.

Experts discussed the possibility that, once data have been collected, external requests for the data could grow quickly, requiring further policy adaptations and changes to clarify who

Officers will need evidence-based programming that helps them *understand* the information collected by wearable sensors and then implement personal strategies and techniques based on that information to improve their well-being.

outside law enforcement agencies can access officers' health data and for what reasons. Experts discussed how many current policies are outdated and require modification to account for new, constantly evolving technologies that generate personally identifiable data. Ideally, experts stated, detailed data should be available only to persons who are deemed necessary to achieve a specific clinical purpose. Experts identified several additional parties, however, who could be likely to request data, including prosecutors, defense attorneys, insurance companies, media, technology companies, and members of the public. It was suggested that more research must be done to understand how third parties could compel disclosure of WST data. This includes issues related to vendor "ownership" of law enforcement data that resides in their cloud and how Freedom of Information Act requests apply.

The participants also discussed how agencies could proactively share aggregate data collected from wearable sensors to demonstrate transparency to the public. For example, some experts imagined a dashboard displaying average heart rates of officers across time and space. However, other experts cautioned that de-identification is difficult, especially as open data become increasingly detailed and increasingly sophisticated machine-learning approaches can be used to glean patterns from those data that can be traced back to specific officers.

Participants advised that, as WSTs are implemented, agencies should develop sustainable policies so that WSTs are used effectively to foster health and wellness. Experts emphasized the importance of planning for evaluations to begin early in the adoption process, start small, and then scale up. This involves having policy to allow for a sequenced, phased approach to adoption so that careful and rigorous evaluations of these new technologies can be conducted. It is critical that agencies assess the impact on key outcomes, such as officers' health and wellness or specific measures of organizational productivity, so that they can determine their return on investment. Process evaluations are also critical, because they can help police leaders determine whether WSTs are ineffective for achieving desired goals or whether there were specific challenges or issues with implementation that affected the technology's usefulness. For example, an agency might learn through an outcome evaluation that measures of officer health are no better after providing WST than before the technology was offered. However, a process evaluation might reveal that officers did not understand how to use or interpret the data that were collected and thus failed to make any meaningful changes to improve their well-being.

Experts agreed that officers will require specific, tailored training on WST. At a minimum, agencies will need to train officers on how to interpret data and metrics. More broadly, officers will need evidence-based programming that helps them *understand* the information collected by wearable sensors and then implement personal strategies and techniques based on that information to improve their well-being. Again, experts highlighted the important role that a legitimate medical authority can play in this type of training. One law enforcement participant's agency hired a physician to coach and mentor personnel to live healthier lives. WSTs could build on programs like this one by providing individualized information so that strategies can be appropriately tailored to each officer. The key is developing individual-level interventions that affect health and wellness and training programs that persuade officers to adopt new behaviors. At the agency level, police leaders will need to identify evidence-based interventions that can improve officers' performance using WST data. For example, one expert explained that this might include optimizing performance during critical incidents through better training, conditioning, and recovery. Experts recommended that agencies help officers by providing guidance on objectively assessing their progress over time in response to different interventions as part of the coaching, mentoring, and evidence-based programming that officers receive. A key need will be to establish appropriate comparisons for gauging progress. For example, officers could be

compared with themselves at a specific baseline; with data from their agency or other, similar agencies; with law enforcement in general; or with the general population. The key is identifying appropriate comparisons and coaching officers to understand their objective progress over time.

Technology and Data

Measurement

The participants were clear that the capabilities of WST are not yet adequate, in terms of functionality, accuracy, reliability, and other factors, to be used in the envisioned law enforcement applications. A major challenge will be managing expectations around WST within law enforcement and among the public. Research on consumer views of wearables suggested that user expectations around the functionality of WST were increasing, but expectations frequently exceeded reality (Ericsson ConsumerLab, 2016). Commercial markets for wearables continue to grow rapidly, and devices are increasingly sophisticated in design, power, and function. Yet, as one expert explained, no devices have thus far been shown to improve a clinical outcome. Generally, existing research on WST is observational, consisting of feasibility assessments that are limited by small sample sizes, poor research designs, and low statistical power. Furthermore, existing studies have not yet determined whether WST data are reliable. Currently, the best measures derived from wearables pertain to physical activity, sedentary behavior, and sleep (Xie et al., 2018).

Another issue is that current artificial intelligence applications cannot make use of the vast and complex data collected by WSTs. Experts largely agreed that agencies would not be using WSTs to make operational decisions in the near term and that a realistic short-term goal would be a better understanding of officers' physical condition, fitness, and readiness. Over the next five years, experts thought that WST would remain largely limited to personally owned devices for individual wellness monitoring. Experts emphasized the value in establishing individual baselines, although rudimentary, to help officers track health changes over their careers, which will become easier as technology improves. For example, participants noted that long-term data can help agencies develop more-effective early warning systems in the future or alert officers to emerging health concerns based on their unique profiles. Experts agreed that it was critical to monitor the state of research to manage expectations around WST in the near term, especially as industries begin to approach police leaders to market and sell their devices. Experts believed that it would be helpful to evaluate WSTs using the U.S. Department of Defense's technology readiness levels to facilitate broader understanding of WSTs and mitigate misconceptions about their capability.[3]

As WSTs constantly evolve, high-quality research will be needed to determine the validity and reliability of each device to help police leaders understand which devices will be most beneficial to their agencies. In the short term, experts recommended that researchers focus on the *validation* (i.e., accuracy of measures) of WST, while the long-term *reliability* (i.e., receiving the same measurement value consistently under identical conditions) of WST data will become more important over time. Currently, studies are needed to establish whether researchers can observe and gather meaningful metrics on health and well-being from different types of devices. Although several feasibility studies already exist, the diversity of methods, outcomes, and devices examined makes it difficult to compare findings. Experts emphasized the need for standardization in feasibility studies. A current resource that might serve as a guide or starting point is the Clinical Trials Transformation Initiative (CTTI) feasibility studies database (CTTI, undated). As form factors, sensors, and the analytic capacity of WST improve, the goal will be to identify devices that are reliable. Experts noted that the rapidly changing landscape of WSTs presents a pacing problem for law enforcement; like cell phones and digital evidence, these technologies are difficult for law enforcement to keep up with (Goodison, Davis, and Jackson, 2015). According to the experts, this highlights the need for a

The rapidly changing landscape of WSTs presents a pacing problem for law enforcement; like cell phones and digital evidence, these technologies are difficult for law enforcement to keep up with.

> "Normal" ranges within a given indicator can vary across demographic groups. Different people's bodies might have substantially different reactions to the same experience.

centralized, independent, and objective broker or clearinghouse for these technologies.

Finally, research is needed on how various sensors and metrics are embedded in WSTs and the implications for measured outcomes, particularly given the diversity in these components observed across wearables and their constant evolution. One expert explained that there are essentially three waves of sensor capabilities: (1) the accelerometer to measure movement and characterize physical activities, (2) biometrics to measure behavioral and physiological indicators, and (3) implantable or *in vivo* devices. Much attention and development has already occurred around accelerometers, and research is rapidly growing around biometrics; *in vivo* devices are nascent and will be the next wave of WST (Guk et al., 2019). Experts agreed that bioanalytics, such as sweat harvesting (i.e., analysis of perspiration for water content, salt, and other chemicals associated with wellness), offer considerable measurement potential but are in the very early stages of development. Experts also noted a desire to see practitioner-friendly systematic reviews to bring together a large, diverse, and complex body of scientific, technical literature.

From the development side, law enforcement will need to fill an important role in helping define a set of best practices for consumer wearable devices. Experts agreed that developers must work with law enforcement to ensure that new devices are consistent with uniform policies, tactical requirements, and data security requirements. The challenge will be to strike a balance between customizing devices to the needs of a particular agency and standardizing devices for use in law enforcement more generally. If devices are too customized, for example, they might interfere with important goals, such as data sharing. Experts recommended working with a diverse set of law enforcement agencies and personnel to develop WSTs with the goal of replicating success in other, similar types of agencies.

Usage

One way to help vendors develop WSTs that benefit law enforcement is by creating a use case framework (RTI International and University of North Carolina at Chapel Hill, 2017). Experts identified several potential use cases of WST in law enforcement, such as daily use in the field, critical incidents, training exercises, off-duty use, monitoring injury recovery, and fitness for duty. For use case development, it is important to understand the primary problems within each well-defined use case, identify key stakeholders and their needs, and then demonstrate how a device or suite of devices can help agencies resolve these problems in ways that are effective. This likely will involve a determination of the specific needs for data accuracy, reliability, and processing for each use case. Determining who will use or be assigned WST devices also will help resolve uncertainty about what form factors and data collection, sharing, and analysis requirements are appropriate. Regarding the latter, vendors can make decisions based on these requirements to reduce the volume of data collected, making it more usable for agencies and minimizing security risks.

Experts also recommended that vendors develop guidance on how to use and interpret metrics for agencies adopting WST. The use case framework can also be helpful in this context because metrics can be interpreted within specific, well-defined scenarios. However, the participants emphasized the importance of clearly defining the limitations of WST interpretation and usage. For example, optical sensors are subject to inaccuracies caused by differences in skin pigmentation or the presence of tattoos, so usage of the data could be suspect. Furthermore, "normal" ranges within a given indicator can vary across demographic groups. One expert explained that one's body reads out the data, but the narrative cannot be determined; different people's bodies might have substantially different reactions to the same experience. Vendors must take steps to make the information provided by WST meaningful for law enforcement.

Vendors must also work with law enforcement to implement appropriate security requirements, including end-to-end encryption protecting WST data at each layer as they move throughout an organization. Each time data move, they create a new attack vector; in law enforcement, this might include data transmission from a wearable device to a patrol vehicle, then to a precinct, and then possibly to a cloud server. Experts agreed that solutions are currently available, but they need to be researched for law enforcement and tailored to law enforcement needs moving forward.

CONCLUSION

WSTs have gained in popularity in recent years, but the devices have yet to play a substantive role within law enforcement. As WSTs continue to evolve, the devices show considerable potential to inform operational decisions that can improve officers' safety (e.g., status monitoring during critical incidents) and foster workforce health and wellness (e.g., shift and staffing assignments), but the technology and policy are not yet sufficiently developed to be effective for these purposes, despite misconceptions to that effect among law enforcement and the general public. Our workshop addressed the salient issues surrounding WST adoption within law enforcement, highlighting the key short-term needs to help lay a foundation for potential acquisition and use by law enforcement. In total, the expert panel identified 33 high-priority needs that could be broadly categorized into one of two major themes. The first theme pertains to policy issues, or activities that law enforcement will lead with regard to WST integration. Within this theme are issues related to *adoption*, or issues and needs around securing officer and public buy-in for WST, and *adaptation*, or policy or programmatic changes required of law enforcement agencies that deploy WST. The second theme pertains to data and technology issues, or activities that will be conducted largely by researchers and developers with meaningful input from law enforcement. Included in this theme are issues related to *measurement*, or how data are collected by WST, and *usage*, or how data are interpreted and used to inform individual-level behaviors or organizational initiatives. The participants uniformly agreed that neither WST nor law enforcement is ready for uses that are tied to operational decisionmaking but highlighted a strong need to lay the policy groundwork now given the high ceiling of potential for WST. Now is the time to plan for the potential implications of WST, while the technology is still developing and personal adoption is increasing. As stakeholders learned from BWC, once the technology is ready and available, a single event could be the spark to start a rush for adoption. Addressing the needs detailed in this report will allow law enforcement to be ready to use WST in a thoughtful and efficient manner if the use trajectory shifts quickly toward acquisition.

TECHNICAL APPENDIX

In this appendix, we present additional details about the workshop agenda and the process for identifying and prioritizing technology and other needs specific to the use of WST in policing policy and practice. Through this process, we developed the research agenda that structured the topics presented in the main report. The descriptions in this appendix are drawn and adapted from those in previous publications of the Priority Criminal Justice Needs Initiative and reflect adjustments to the needs identification and prioritization process implemented at this workshop.

Pre-Workshop Activities

We recruited panel members by identifying knowledgeable individuals through existing professional and professional social networks (e.g., LinkedIn) and by reviewing literature published on the topic. Potential attendees were divided into four categories: law enforcement, academia, public policy and privacy experts, and creators of WST. For this workshop, we identified an initial sample of 36 potential attendees. We then extended an invitation to those individuals and provided a brief description of the workshop's focus areas. A total of 11 voting participants attended the workshop.

In advance of the workshop, we gave participants an opportunity to identify the issues and topics that they felt would be important to discuss during the workshop. We structured the workshop agenda and discussion as shown in Table A.1 based on a comprehensive literature review and input from the workshop participants.

Identification and Prioritization of Needs

During the workshop, we asked the participants to discuss the challenges that they or the practitioners they work with face. We also asked them to identify areas where additional research and development investment could help alleviate the challenges. During these discussions, participants suggested additional areas that are potentially worthy of research or

Table A.1. Workshop Agenda

Day 1	Day 2
Welcome, Overview, and Introductions	Review of Day 1 and Brainstorming Session
Initial Discussion of the Current State of Wearables	Final Needs Prioritization
Discussion of Wearable Sensor Technology and Law Enforcement (Individual Level)	Wrap-Up and Next Steps
Prioritization Review and Initial Discussion	
Wearable Sensor Technology (Agency Level)	
Privacy, Ownership, and the Public	

investment. Participants also considered whether there were areas that were not included in the existing list and suggested new ones. Although the process of expert elicitation that we describe in this appendix was designed to gather unbiased, representative results from experts and practitioners in the field, we note several limitations that could affect the findings. The process typically elicits opinions from a relatively small group of experts. As a result, although we attempted to make the group as representative as possible of different disciplines, perspectives, and geographic regions, the final output of the workshop likely will be significantly influenced by the specific group of experts invited to participate. It is possible that the findings from the workshop would vary were a different group of experts selected. Moreover, although the discussion moderators made every effort to act as neutral parties when eliciting opinions from the collected experts, the background and experience of the moderators had the potential to influence which questions they posed to the group and how they phrased those questions. This also could introduce bias that could influence the findings.

To develop and prioritize a list of technology and policy issues that are likely to benefit from research and investment, we followed a process similar to one that has been used in previous Priority Criminal Justice Needs Initiative workshops (see, for example, Jackson et al., 2015; Jackson et al., 2016, and references therein). The needs were prioritized using a variation of the Delphi Method, a technique developed at RAND to elicit expert opinion about well-defined questions in a systematic and structured way (RAND Corporation, undated). Participants discussed and refined problems related to each category and identified potential solutions (or *needs*) that could address each problem. In addition, needs could be framed in response to opportunities to improve performance by adopting or adapting a new approach or practice (e.g., applying a new technology or tool in the sector that had not been used before).

At the end of the discussion of each topic, participants were given an opportunity to review and revise the list of problems and opportunities that they had identified. The participants' combined lists for each topic were displayed one by one using Microsoft PowerPoint slides that were edited in real time to incorporate participant revisions and comments.

Once the participants agreed on the wording of each slide, we asked them to anonymously vote using a handheld device (specifically, the ResponseCard RF LCD from Turning Technologies). Each participant was asked to individually score each problem or opportunity and its associated needs using a 1–9 scale for two dimensions: importance and probability of success.

For the *importance* dimension, participants were instructed that 1 was a low score and 9 was a high score. Participants were told to score a need's importance with a 1 if it would have little or no impact on the problem and with a 9 if it would reduce the impact of the problem by 20 percent or more. Anchoring the scale with percentage improvements in the need's performance is intended to help make rating values more comparable from participant to participant.

For the *probability of success* dimension, participants were instructed to treat the 1–9 scale as a percentage chance that the need could be met and broadly implemented successfully within the tangible future. That is, they could assign the need's chance of success between 10 percent (i.e., a rating of 1) and 90 percent (i.e., a rating of 9). This dimension was intended to include not only technical concerns (i.e., whether the need would be hard to meet) but also the effect of factors that might lead law enforcement to not adopt the new technology, policy, or practice even if it was developed. Such factors could include, for example, cost, staffing concerns, and societal concerns.

After the participants rated the needs displayed on a particular slide (i.e., for either importance or probability of success), we displayed a histogram-style summary of participant responses. If there was significant disagreement among the participants (the degree of disagreement was determined by the research team's visual inspection of the histogram), they were

asked to discuss or explain their votes at one end of the spectrum or the other. If a second round of discussion occurred, participants were given an opportunity to adjust their ratings on the same question. This second-round rating was optional, and any rating submitted by a participant would replace his or her first-round rating. This process was repeated for each question and dimension at the end of each topic area. Figure A.1 shows an example of a slide on the importance dimension, with related issue, need, and histogram. Figure A.2 shows a slide on the probability of success dimension.

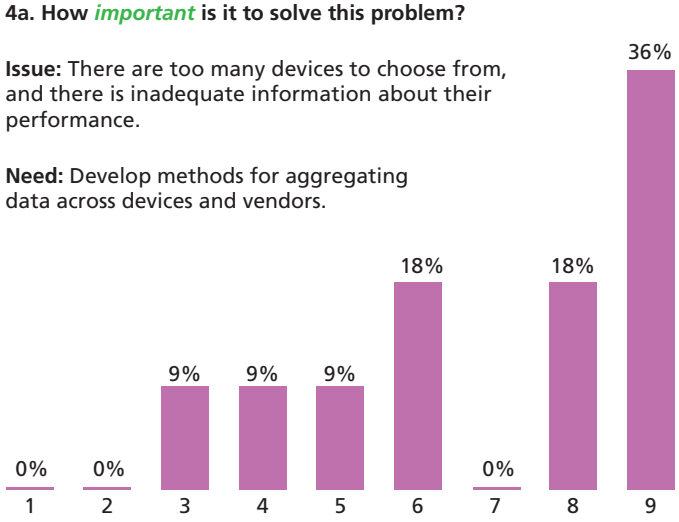
Once the participants had completed this rating process for all topic areas, we put the needs into a single prioritized list. We ordered the list by calculating an expected value using the method outlined in Jackson et al., 2016. For each need, we multiplied the final (second-round) ratings for importance and probability of success to produce an expected value. We then calculated the median of that product across all of the respondents and used that as the group's collective expected value score for the need.

We clustered the resulting expected value scores into three tiers using a hierarchical clustering algorithm. The algorithm we used was the "ward.D" spherical algorithm from the "stats" library in the R statistical package, version 3.5. We chose this algorithm to minimize within-cluster variance when determining the breaks between tiers. The choice of three tiers is arbitrary but was done in part to remain consistent across the set of technology workshops that we have conducted for NIJ. Also, the choice of three tiers represents a manageable system for policymakers. Specifically, the top-tier needs are the priorities that should be the primary policymaking focus, the middle-tier needs should be examined closely, and the bottom-tier needs are probably not worth much attention in the short term (unless, for example, they can be addressed with existing technology or approaches that can be readily and cheaply adapted to the identified need).

Because the participants initially rated the needs one topic area at a time, we gave them an opportunity at the end of the workshop to review and weigh in on the tiered list of all identified needs. The intention of this step was to let the panel members see the needs in the context of the other tiered needs and allow them to consider whether there were some that appeared too high or low relative to the others. To collect these assessments, we printed the entire tiered list and distributed it to the participants. This step allowed the participants to see all of the ranked needs collected across the day-and-a-half workshop, providing a top-level view that is complementary to the rankings provided session by session. Participants were then asked to examine where each of the needs landed on the overall tiered list and whether this ordering was appropriate or needed fine-tuning. Participants had the option to indicate whether each problem and need pairing should be voted up or down on the list. An example of this form is provided in Table A.2.

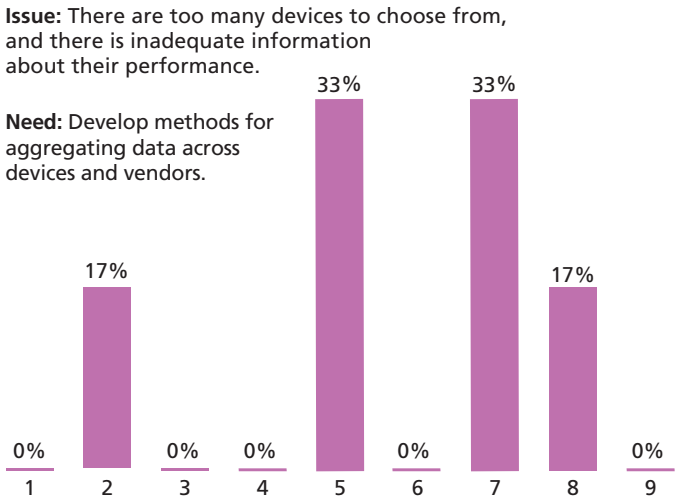
We then tallied the participants' third-round responses and applied those votes to produce a final list of prioritized

Figure A.1. Example Slide for Rating the Importance of a Need



NOTE: Percentages on each question did not always sum to 100 percent because of rounding and variation in the number of participants who voted on each need.

Figure A.2. Example Slide for Rating the Probability of Success of a Need



NOTE: Percentages on each question did not always sum to 100 percent because of rounding and variation in the number of participants who voted on each need.

Table A.2. Example of the Delphi Round 3 Voting Form

Question	Tier	Vote Up	Vote Down
Tier 1			
Issue: The effectiveness of using the technology to improve officer safety and wellness is uncertain. **Need:** Develop a sequenced or phased approach to taking validated technology to the field for scaled evaluations.	1		
Issue: WST data are sensitive, personal information and need to be protected by strong security. **Need:** Encrypt data at each layer and employ end-to-end encryption.	1		
Tier 2			
Issue: The costs of WST (e.g., start-up, data storage, maintenance, analysis, training, equipment) are significant. **Need:** Identify funding mechanisms and opportunities (e.g., grants, budgeting, partnerships).	2		
Issue: There are challenges surrounding the willingness of law enforcement agencies and officers to wear and use WST. **Need:** Partner with insurance companies and health care systems to create incentives and opportunities for reducing premiums by promoting WST.	2		
Tier 3			
Issue: There are too many devices to choose from, and there is inadequate information about their performance. **Need:** Develop methods for aggregating data across devices and vendors.	3		
Issue: Laws and regulations are outdated when it comes to handling digital data. **Need:** Make changes to data use policies, regulations, and laws akin to the changes made for BWC.	3		

NOTE: Shaded cells indicate that up or down votes were not possible (e.g., Tier 1 is the top tier, so it was impossible to upvote items in that tier).

and tiered needs. To adjust the expected values using the up and down votes from the third round of prioritization, we implemented a method equivalent to the one we used in previous work (Hollywood et al., 2016). Specifically, if every panel member voted "up" for a need that was at the bottom of the list, then the collective effect of those votes should be to move the need to the top. (The opposite would happen if every panelist voted "down" for a need that was at the top of the list.) To determine the point value of a single vote, we divided the full range of expected values by the number of participants voting.

To prevent the (somewhat rare) situation in which small numbers of votes have an unintended outsized impact—for example, when some or all of the needs in one tier have the same or very similar expected values—we also set a threshold that at least 25 percent of the workshop participants must have voted on that need (and then rounded to the nearest full participant). For this workshop, there were 11 participants, so for any votes to have an effect, at least four participants would have had to have voted to move the need up or down.

After applying the up and down vote points to the second-round expected values, we compared the modified scores with the boundary values for the tiers to see whether the change was enough to move any needs up or down in the prioritization. (Note that there were gaps between these boundaries, so some of the modified expected values could fall in between tiers. See Figure A.3.) As with prior work, we set a higher bar for a need to move up or down two tiers (from Tier 1 to Tier 3, or vice versa) than for a need to move to the tier immediately above or below. Specifically, a need could *increase by one tier* if its modified expected value was higher than the highest expected value score in its initial tier. And a need could *decrease by one tier* if its modified expected value was lower than the lowest expected value in its initial tier. However, to *increase or decrease by two tiers* (which was possible only for needs that started in Tier 1 or Tier 3), the score had to increase or decrease by an amount that fully placed the need into the range two tiers away. For example, for a Tier 3 need to jump to Tier 1, its expected value score had to fall within the boundaries of Tier 1, not just within the gap between Tier 1 and Tier 2. See Figure A.3, which illus-

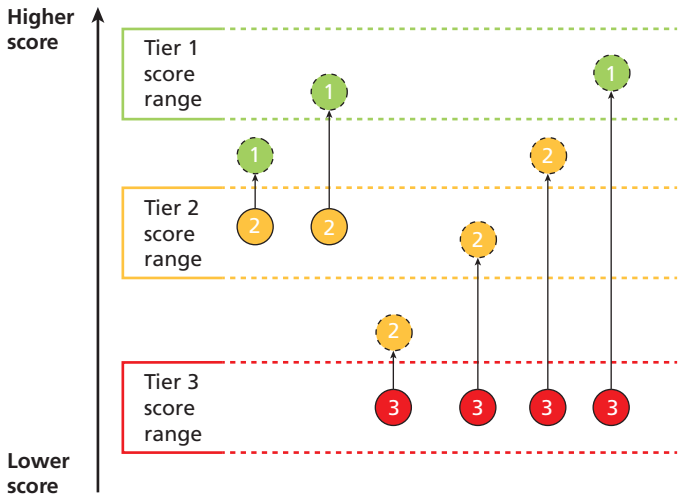
trates the greater score change required for a need to move two tiers (one need on the far right of the figure) compared with one tier (all other examples shown).

Applying these decision rules to integrate the participants' third-round inputs into the final tiering of needs resulted in numerical separations between tiers that were less clear than the separations that resulted when we used the clustering algorithm in the initial tiering. This can occur because, for example, when the final expected value score for a need that was originally in Tier 3 falls just below the boundary value for Tier 1, that need's final score could be higher than that of some other needs in the item's new tier (Tier 2). See Figure A.4, which shows the distribution of the needs by expected value score after the second-round rating process and then after the third-round voting process.

As a result of the third round of voting, 44 needs did not change their position, 13 needs rose by one tier, and four needs fell by one tier. No needs changed by two tiers. The output from this process became the final ranking of the panel's prioritized results.

The complete list of identified needs is shown in Table A.3, and the needs are sorted by tier and theme. Of the 61 identified needs,

Figure A.3. How a Need's Increase in Expected Value Might Result in Its Movement Across Tier Boundaries



NOTE: Each example need's original tier is shown by a circle with a solid border (the two needs starting in Tier 2 and the four needs starting in Tier 3). Each need's new tier after the third-round score adjustment is shown by the connected circle with a dotted border.

- 17 were related to policy adoption
- 24 were related to policy adaptation
- 13 were related to technology and data measurement
- seven were related to technology and data usage.

Figure A.4. Distribution of the Tiered Needs Following Rounds 2 and 3

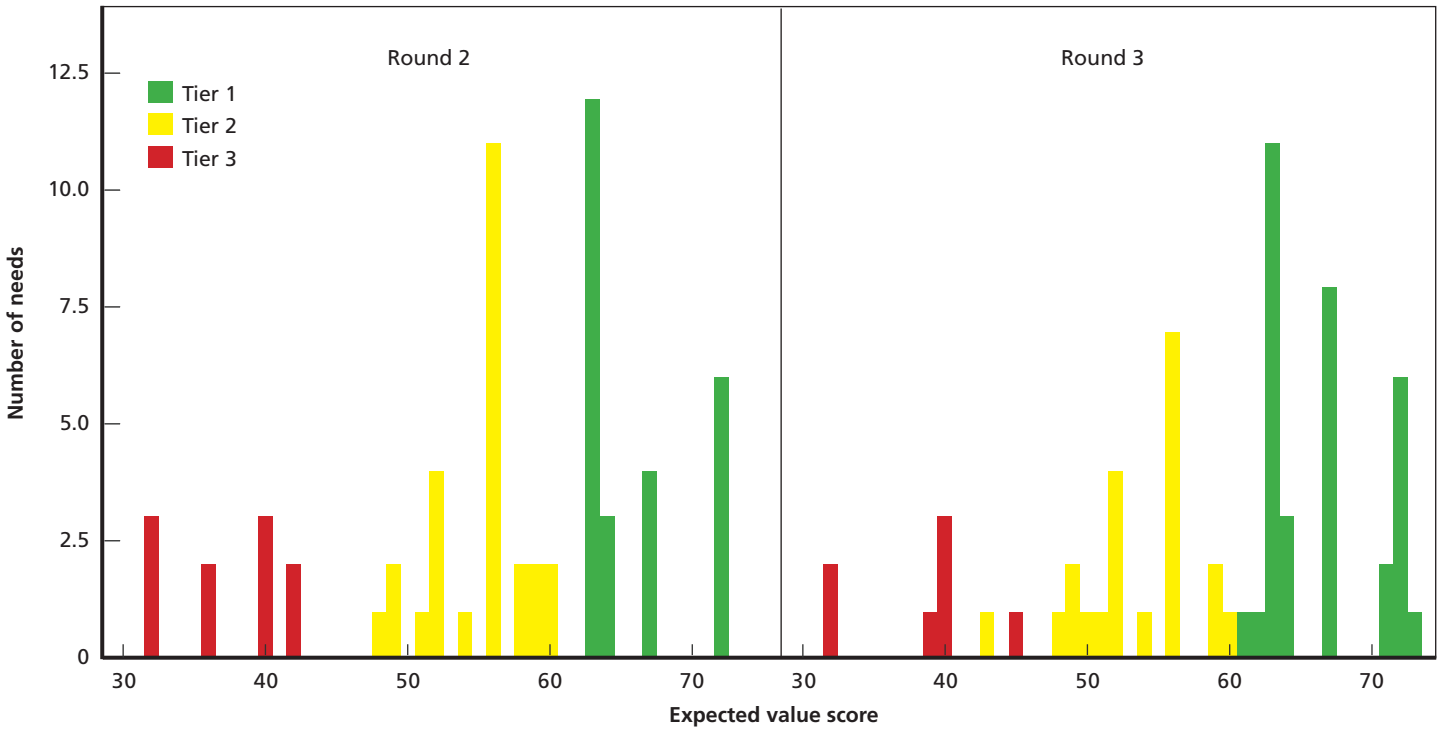


Table A.3. Complete List of Needs, by Tier

Problem or Opportunity	Need	Tier
Policy adoption		
It might be challenging to achieve acceptance and utility of WST-based programs or initiatives at the agency level.	• Identify outcome measures early in the process.	1
The costs of WST (e.g., start-up, data storage, maintenance, analysis, training, equipment) are significant.[a]	• Conduct research on return on investment of WST.	
Law enforcement agencies and officers have shown a willingness to wear and use WST.[a]	• Secure buy-in through policy protections. • Conduct training to acclimate officers to WST. • Educate officers on potential positive and negative uses of WST. • Educate officers on the multiple uses and purposes of WST. • Conduct pilot testing and collect feedback on experiences.	
New officers or recruits might have different expectations for a policing career, are potentially more aware of their health, and might be willing to try new technology.[a]	• Introduce WST in academy training to increase acceptability. • Encourage departments to make it known that they care about officers and officer health. • Increase self-awareness by encouraging officers to track themselves at home to collect baseline or resting data.	
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Take a systematic approach to deciding what device or product to use.	
Policy adaptation		
WST data are sensitive, personal information and need to be protected by strong security.[a]	• Adopt and implement policy and process controls. • Treat WST data like other law enforcement–sensitive data.	1
It is difficult to change officer behavior without the ability to provide assessment of "how they are doing" over time.[a]	• Provide support for officers through coaching, mentorship, and evidence-based programming.	
Some fear that WST data would be used against law enforcement officers.	• Partner with labor associations. • Develop and implement policies and processes for when and why data may be shared.	
Demand from other entities and stakeholders to access WST data is increasing.	• Establish policies for when to collect data, how often to collect data, how to retain data, and how to secure data. • Develop and implement policies for data sharing (i.e., what data should be shared, when, why, how, and with whom). • Understand how third parties (e.g., litigious agencies) could compel disclosure of data.	
There is uncertainty about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Implement guidance and education for users on how to interpret data and metrics.	
There has been a shift in how law enforcement takes care of its personnel, and greater attention has been paid to officer safety and wellness, with a focus on creating better conditions for officers so that they can do their jobs better and for longer periods of time.	• Provide coaching, mentoring, and evidence-based programming for officers to help them understand the information and data and techniques for using them to make improvements.	
The effectiveness of using the technology to improve officer safety and wellness is uncertain.	• Develop a sequenced or phased approach to taking validated technology to the field for scaled evaluations.	
Technology and data measurement		
Individualizing or personalizing data metrics that come from WST is challenging.	• Establish individual baselines to account for differences across the individual.	1

Table A.3—Continued

Problem or Opportunity	Need	Tier
There are general misconceptions that WST is more advanced than it is, and there is public confusion about WST.[a]	• Evaluate technologies based on technology readiness levels. • Monitor the state of the research and manage law enforcement and public expectations.	
Uncertainty remains about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Conduct validation studies on existing sensor technology. • Review literature; conduct research on tests, sensors, biometrics, and bioanalytics and how they inform selected outcomes; or do both.	
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Conduct validation studies of WST devices, and conduct reliability studies as technology changes. • Define a set of best practices for consumer wearable devices.	
Technology and data usage		
WST data are sensitive, personal information and need to be protected by strong security.[a]	• Encrypt data at each layer and employ end-to-end encryption.	1
Uncertainty remains about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Develop guidance and education for users on how to interpret data and metrics. • Determine users and uses of WST devices and data.	
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Develop a framework for uses of devices and data (e.g., use cases).	
Policy adoption		
It might be challenging to achieve acceptance and utility of WST-based programs or initiatives at the agency level.[a]	• Demonstrate that agency leadership understands the value of WST and will promulgate appropriate policies.	2
The costs of WST (e.g., start-up, data storage, maintenance, analysis, training, equipment) are significant.[a]	• Identify funding mechanisms and opportunities (e.g., grants, budgeting, partnerships).	
There are challenges surrounding the willingness of law enforcement agencies and officers to wear and use WST.[a]	• Conduct needs assessment for WST, and collect officer input.	
New officers or recruits might have different expectations for a policing career, are potentially more aware of health, and might be willing to try new technology.[a]	• Introduce WST in academy training to collect baseline data and establish opportunities for intervention.	
Policy adaptation		
It might be challenging to achieve acceptance and utility of WST-based programs or initiatives at the agency level.[a]	• Conduct research on what types of interventions work.	2
There is a need for an organizational advocate for privacy and decisionmaking because of changes in technology and policy.	• Consult with or identify a privacy officer or entity to fulfill that role.	
WST might violate uniform policy.	• Adapt policy to address the need for WST.	
It is difficult to change officer behavior without the ability to provide assessment of "how they are doing" over time.[a]	• Identify and evaluate existing officer health and safety programs. • Enhance legacy officer health and safety programs with current, objective information about WST.	

Problem or Opportunity	Need	Tier
There are challenges surrounding the willingness of law enforcement agencies and officers to wear and use WST.[a]	• Partner with insurance companies and health care systems to create incentives and opportunities for reducing premiums by promoting WST.	
Variation in law enforcement agencies across the country highlights the differences in feasibility of implementing WST across rural and metropolitan departments.[a]	• Adapt best practices to tailor implementation to meet the needs of each agency.	
There is uncertainty about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Address discrimination and negative uses of data (e.g., claim denial, coverage changes, job loss, denial of promotion). • Stay abreast of other existing technologies for monitoring stress and mental health.	
There are general misconceptions that WST is farther along than it is, and there is public confusion about WST.[a]	• Increase transparency between law enforcement and the public about wearables and how they could improve interactions between police and the public.	
There is a lack of clarity regarding whether any WST in law enforcement could be subject to public information requests.	• Determine whether and when WST information and data have public value.	
Technology and data measurement		
WST is rapidly advancing, and assessments often do not keep up with technology pacing.	• Develop and maintain a centralized clearinghouse for information about the technology.	2
Variation in law enforcement agencies across the country highlights the differences in feasibility of implementing WST across rural and metropolitan departments.[a]	• Have law enforcement from rural and metropolitan departments become more involved with standards development organizations to develop standards for law enforcement.	
There is uncertainty about what can be measured, what should be measured, and what WST metrics are most meaningful and relevant for law enforcement.[a]	• Conduct hypothesis-driven research on the level of data accuracy needed.	
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Define wearables by regulatory profile and by what they are intended to measure.	
Technology and data usage		
There is a risk of data overload from real-time feedback to officers.	• Prioritize when feedback is needed and when it is not.	2
Variation in law enforcement agencies across the country highlights the differences in feasibility of implementing WST across rural and metropolitan departments.[a]	• Encourage vendors to have scalable costs for WST and consider public-private partnerships.	
Policy adoption		
There are challenges surrounding the willingness of law enforcement agencies and officers to wear and use WST.[a]	• Make WST a requirement upon hiring, as part of the contract for employment.	3
New officers or recruits might have different expectations for a policing career, are potentially more aware of health, and might be willing to try new technology.[a]	• Ask new recruits what they think about WST and about their willingness to use it.	
Policy adaptation		
Laws and regulations are outdated when it comes to handling digital data.	• Make changes to data use policies, regulations, and laws akin to the changes made for BWC.	3
Variation in law enforcement agencies across the country highlights the differences in feasibility of implementing WST across rural and metropolitan departments.[a]	• Encourage larger agencies to carve out resources for officer safety and wellness from their budgets to provide resource opportunities for other agencies.	

Problem or Opportunity	Need	Tier
Technology and data measurement		
Laws and regulations are outdated when it comes to handling digital data.	• Gauge public opinion about new technologies and data gathering in general and as they apply to law enforcement.	3
There are too many devices to choose from, and there is inadequate information about their performance.[a]	• Develop methods for aggregating data across devices and vendors.	
Technology and data usage		
There are interoperability issues surrounding devices and data, including how the device communicates with other devices that need to have the information or data, what network is needed to do so, and how the application or data are displayed so that they are meaningful.	• Explore capabilities for communicating between devices and across authorized receivers of data.	3

[a] This problem or opportunity is associated with needs that fell into different tiers.

Notes

[1] We define *wearability* as a qualitative measure of the comfort of a worn device. We define *validity* as a quantitative measure of the accuracy of data gathered by a device (e.g., did the device accurately measure the user's heart rate?). We define *reliability* as a quantitative measure of the measurement consistency across different tests, users, or activities (e.g., did a device measure the number of steps with the same accuracy for different users?).

[2] For example, see Department of Commerce Internet Policy Task Force, 2010.

[3] *Technology readiness levels* refer to a numeric scale, from 1 to 9, for estimating the maturity of a technology in defense acquisitions. For more information, see Institute of Medicine and National Research Council, 2014.

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RAND Social and Economic Well-Being is a division of the RAND Corporation that seeks to actively improve the health and social and economic well-being of populations and communities throughout the world. This research was conducted in the Justice Policy Program within RAND Social and Economic Well-Being. The program focuses on such topics as access to justice, policing, corrections, drug policy, and court system reform, as well as other policy concerns pertaining to public safety and criminal and civil justice. For more information, email justicepolicy@rand.org.

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About This Report

On behalf of the U.S. Department of Justice, National Institute of Justice (NIJ), the RAND Corporation, in partnership with the Police Executive Research Forum (PERF), RTI International, and the University of Denver, is carrying out a research effort to assess and prioritize technology and related needs across the criminal justice community. This research effort, called the Priority Criminal Justice Needs Initiative, is a component of the Criminal Justice Requirements & Resources Consortium (RRC) and is intended to support innovation within the criminal justice enterprise. For more information about the RRC and the Priority Criminal Justice Needs Initiative, please see www.rand.org/well-being/justice-policy/projects/priority-criminal-justice-needs.

In September 2019, PERF and RAND conducted an expert workshop to address potential uses of wearable sensor technology to improve law enforcement officer safety and wellness. This report presents the proceedings of that workshop, topics considered, needs that the panel participants developed, and overarching themes that emerged from the panel discussions. This report and the results it presents should be of interest to law enforcement agencies, technology manufacturers, the research community focused on officer health, and public policy and privacy advocates involved in the collection and use of health data.

Other RAND research reports from the Priority Criminal Justice Needs Initiative that might be of interest are

- Richard Silberglitt, Andrew Lauland, Michael Watson, Christopher A. Eusebi, and Jesse Lastunen, *Wearable Technologies for Law Enforcement: Multifunctional Vest System Options*, Santa Monica, Calif.: RAND Corporation, RR-2012-NIJ, 2017.
- John S. Hollywood, Sean E. Goodison, Dulani Woods, Michael J. D. Vermeer, and Brian A. Jackson, *Fostering Innovation to Respond to Top Challenges in Law Enforcement: Proceedings of the National Institute of Justice's 2018 Chiefs' Panel on Priority Law Enforcement Issues and Needs*, Santa Monica, Calif.: RAND Corporation, RR-2930-NIJ, 2019.

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